

13TH FLUID MECHANICS AND FLUID POWER
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KEYNOTE ADDRESS

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"THE PROSPECTS FOR TURBULENCE
MANAGEMENT"

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THE PROSPECTS FOR TURBULENCE MANAGEMENT*

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The enormous increase in the price of oil that occurred in 1973 has changed the priorities for aeronautical research in a very significant way. While before that date fuel costs accounted typically for about 20 per cent of the operating cost of an airline, the fraction now is of the order of 60 per cent. Energy efficiency has therefore become a major goal in aeronautical technology. Although this can be influenced by developments in a variety of areas such as new materials, engines and propellers, our concern in this lecture will be those developments in aeronautical fluid dynamics that may contribute to improving the energy economy of aircraft.

Historically, we can view aeronautical development in the last 40 years at least as being driven by the need to overcome what were seen during each period as "barriers" to further development. In the 1940s and 1950s there was the "sonic barrier". As this was overcome, a "thermal barrier" became evident as supersonic speeds led to high surface temperatures because of kinetic heating. It appears as if in the 1970s and

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1980s, it is the "turbulence barrier" that has to be tackled as the next major problem confronting aircraft designers. The basic research that has been carried out in the structure of turbulent flows over the last 30 years has suggested new methods of turbulence management, and vigorous research is now taking place to see what the most effective methods are for achieving the desired goals.

It must first of all be understood that turbulence may, in many cases, be desirable. The vigorous mixing that is associated with the turbulent state is often of great value, for example in heat exchangers and in flows in which separation needs to be prevented. The classic experiment of Wieselsberger, in which a ring trip placed on the front of a sphere was shown to reduce the drag of the sphere significantly, is one example where promotion of turbulence could be beneficial. The subject of major interest in this lecture, however, is the possibility of reducing skin friction drag. It has been estimated that if the drag of the fuselage of an aircraft could be reduced by 20 per cent, US airlines will save more than a billion dollars each year. It is clear therefore that at the present prices of fuel, even reduction of drag of an aircraft by a few per cent may be considered worthwhile by a designer.

There are basically three different concepts which may be followed in the effort to reduce drag. The first is laminar flow technology. Here the goal is to delay transition to turbulent

flow and maintain laminar flow as far downstream as possible. An attractive method of doing this is by suction at the surface. This is by no means new; in the 1950s there was a vigorous research programme on boundary layer suction particularly in the US and UK. For a variety of operational and technical reasons, however, this effort was abandoned in the later 1950s; looking back on that period now, it is possible to see that at that time oil was still too cheap for sophisticated new fluid-dynamical technology to be worthwhile on aircraft.

One recent development that has great potential is the possibility of active control of transition. The idea here is that, as the instability waves develop in the laminar flow, a control signal is applied at the right place and the right time (i.e. at the right phase in the instability cycle) to suppress the growth of the instability. This has been demonstrated by the use of surface heating in water flow. Looking into the future, one may visualise under-water vehicles whose surface will look like a printed circuit board, with a large number of surface film elements some of which will act as detectors sending signals through a computer to other films which act as controllers.

The second concept is to relaminarise an initially turbulent flow. It has become clear here that there is a vast number of agencies that can force a turbulent flow back to a laminar or quasi-laminar state. It is useful here to distinguish between hard laminarisation (in which turbulent intensities eventually vanish altogether) and soft laminarisation (in which turbulent

transport may not necessarily vanish, but becomes irrelevant to the dynamics of the mean flow). Both kinds of laminarisation have their applications, and there are different methods for achieving them. In the first, which may be called dissipative, the turbulent energy gets converted to heat through the action of some kind of friction parameter, e.g. viscosity or resistivity. In the second, which may be called absorptive, the energy gets converted to a form of potential energy; e.g. a vertical jet issuing into a fluid with a stabilising density gradient can have its turbulent energy transformed to gravitational energy. A third class may be called dominative where turbulent transport does not vanish but is dominated by other mechanisms that are imposed on the flow; e.g. in a large favourable pressure gradient the absolute value of the turbulent energy tends to remain a constant along each stream line but diminishes as a fraction of the free stream dynamic pressure so that eventually the flow is very largely an inviscid but rotational outer layer riding on top of a thin laminar sub-boundary-layer. Experiment shows that dissipative reversion tends to be hard but slow; absorptive reversion tends to be hard and fast; and dominative reversion is soft and often determined by the rate at which the external agency acts on the flow.

The third concept involves turbulence manipulation. Here turbulence is not necessarily suppressed but its structure is sought to be modified in favourable ways. A large number of devices have been tried to achieve this objective. For example,

surface grooves with a width of about 10-20 wall units seem to yield a reduction of about 5 per cent in the friction drag. The use of polymer to reduce friction is well-known and has been extensively studied. The possibility of obtaining potential benefits by introducing ribbons in the boundary layer has also attracted a great deal of attention. Much careful work is needed in this area before one can be certain what the benefits are, as the saving in drag which is observed is not so high that one can be sure that experimental uncertainties are insignificant.

Some kinds of turbulence management devices, such as for example vortex generators, have been used for a long time in aircraft design. However the new kind of manipulation that is now being studied is something which holds promise but needs much more study. I believe the chances are good that in the next 10 years some new methods of turbulence management will enter aeronautical (and other) technologies.

PRESENTATION SHEETS

DRAG REDUCTION

Speed barriers

Thermal barriers

The TURBULENCE BARRIER

Basic research in the structure of
turbulent flows over the last 30 years

Prospects for new methods of
TURBULENCE MANAGEMENT

Possible mechanisms:

DISSIPATION (turb. energy \rightarrow Heat

ABSORPTION (turb. energy \rightarrow gravity
(e.g.

DOMINATION (turb. energy

\ll new agency

'Throwing a monkey wrench into
the works' ?

3 DIFFERENT CONCEPTS

1 LAMINAR FLOW TECHNOLOGY

- maintain laminar flow,
delay transition

E.g. Suction

Surface heating

2. RELAMINARIZATION

- initially turbulent flow, forced
to laminar or 'quasi-laminar' state

Hard relam: Turbulent intensities

→ 0

Soft relam: Turbulent transport may
remain, but irrelevant
to mean flow dynamics

E.g. Enhanced dissipation (lower Re)

Suction

Favourable pressure gradients

Buoyancy

Curvature

Magnetic fields

R66304

LAMINARIZATION

(At least) 3 possible ways.

1. DISSIPATION

Viscous, ohmic, conductive etc.

(Molecular transport parameter involved)

Dissipation becomes $>$ Production

Turb. kinetic energy \rightarrow Heat

2. ABSORPTION

Turb. kinetic energy \rightarrow (Some form of)
potential energy
(e.g. gravity)

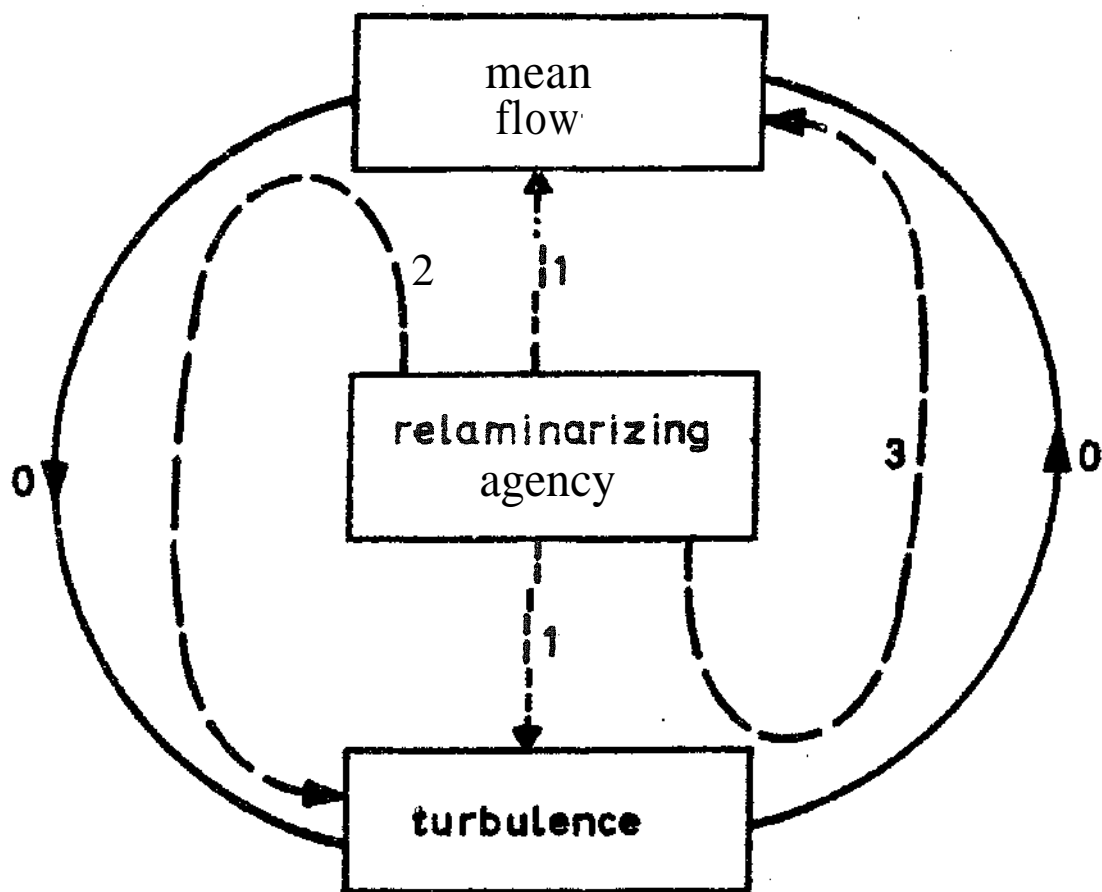
3. DOMINATION

Turb. kin. energy NOT NECESSARILY LOST

but: turbulent transport RENDERED
IRRELEVANT.

\rightarrow "SOFT" LAMINARIZATION.

(Contrast "HARD" LAMINARIZATION
from DISSIPATION, ABSORPTION)



3. TURBULENCE MANIPULATION

- turbulence not necessarily suppressed,
but its structure modified

Surface devices:

- Grooves, riblets
- Heating, cooling
- Mass transfer
- Compliant surface
- Exciters, spot generators
- Additives

Outer flow devices:

- Splitter plates
- Honey combs

Global agents

- 'Surface curvature
- Pressure gradients